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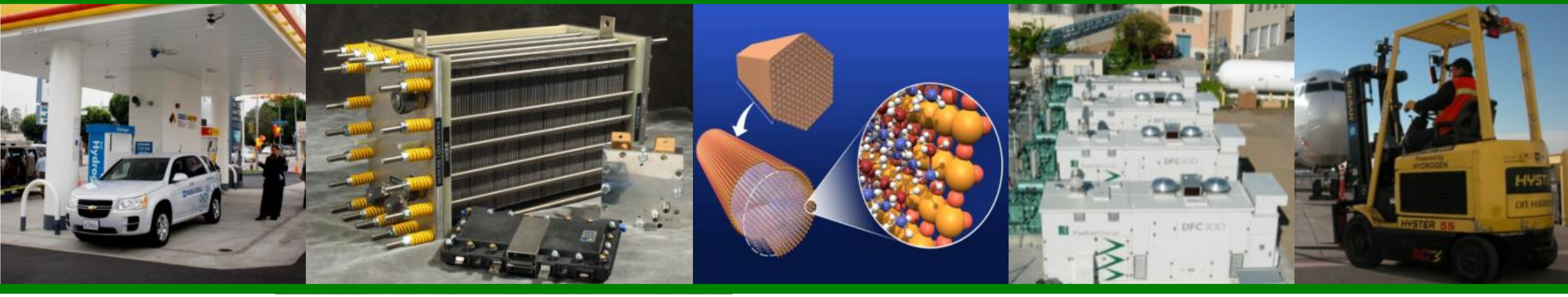

Fuel Cells Sub-program
- Session Introduction -

Dimitrios Papageorgopoulos

2012 Annual Merit Review and Peer Evaluation Meeting

May 15, 2012

Goal and Objectives

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GOAL: Develop and demonstrate fuel cell power system technologies for stationary, portable, and transportation applications

Objectives

- By 2015, a fuel cell system for portable power (<250 W) with an energy density of 900 Wh/L
- By 2017, a 60% peak-efficient, 5,000 hour durable, direct hydrogen fuel cell power system for transportation at a cost of $30/kW
- By 2020, distributed generation and micro-CHP fuel cell systems (5 kW) operating on natural gas or LPG that achieve 45% electrical efficiency and 60,000 hours durability at an equipment cost of $1500/kW
- By 2020, medium-scale CHP fuel cell systems (100 kW–3 MW) with 50% electrical efficiency, 90% CHP efficiency, and 80,000 hours durability at an installed cost of $1,500/kW for operation on natural gas, and $2,100/kW when configured for operation on biogas
- By 2020, APU fuel cell systems (1–10 kW) with a specific power of 45 W/kg and a power density of 40W/L at a cost of $1000/kW

Challenges & Strategy

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The Fuel Cells sub-program supports research and development of fuel cell and fuel cell systems with a primary focus on reducing cost and improving durability. Efforts are balanced to achieve a comprehensive approach to fuel cells for near-, mid-, and longer-term applications.

Fuel Cell MYRD&D recently updated:
http://www1.eere.energy.gov/hydrogenandfuelcells/mypp/index.html

Barriers

Cost
Durability
Performance

→

Strategy

Materials, components, and systems R&D to achieve low-cost, high-performance fuel cell systems

→

Fuel Cell R&D

↕

Testing and Cost/Technical Assessments

→

FOCUS AREAS

Stack Components
Catalysts
Electrolytes
MEAs, Gas diffusion media, and Cells
Seals, Bipolar plates, and Interconnects

Operation and Performance
Mass transport
Durability
Impurities

Systems and Balance of Plant (BOP)
BOP components
Stationary power
Fuel processor subsystems
Portable power
APUs and emerging markets

R&D portfolio is technology neutral and includes different types of fuel cells.

Challenges and Strategy: Automotive Applications

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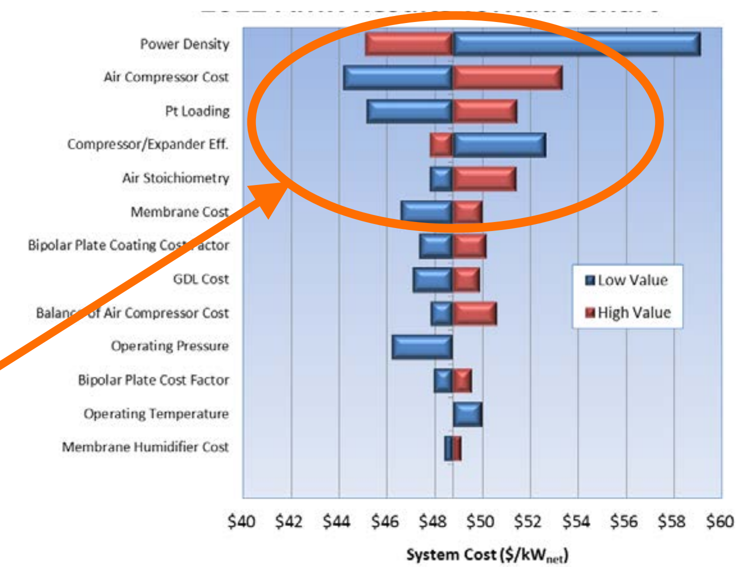
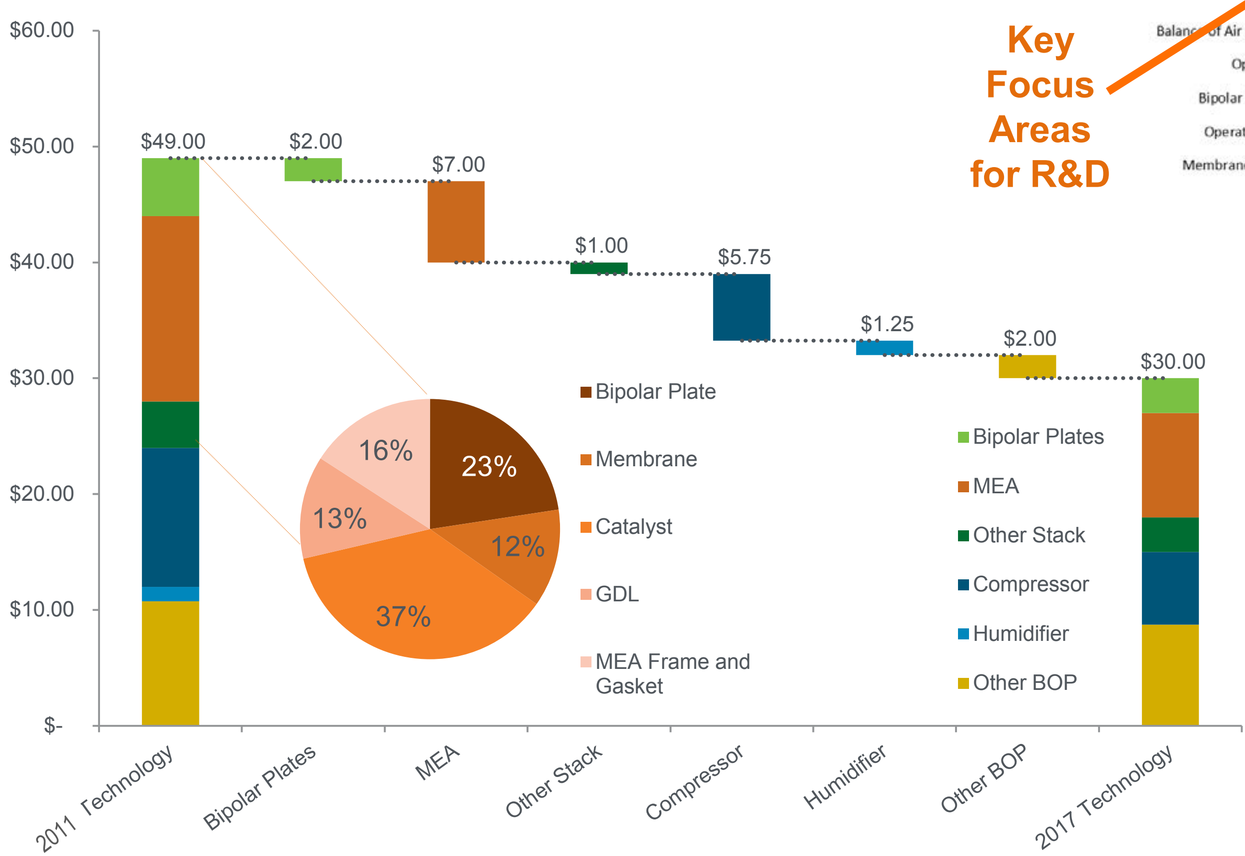
- ***Strategic technical analysis guides focus areas for R&D and priorities.***
- ***Need to reduce cost from $49/kW to $30/kW and increase durability from 2,500 to 5,000 hours***
- ***Advances in PEMFC materials and components could benefit a range of applications.***

Sensitivity Analysis helps guide R&D



Key Focus Areas for R&D



Targeted 80 kW PEM fuel cell system cost: $30/kW at 500,000 units/yr

Strategies to Address Challenges – Catalyst Examples

- Lower PGM Content
- Pt Alloys
- Novel Support Structures
- Non-PGM catalysts

Challenges and Strategy: New Stationary Cost Analysis

Analysis highlights need for fuel processor cost reduction.

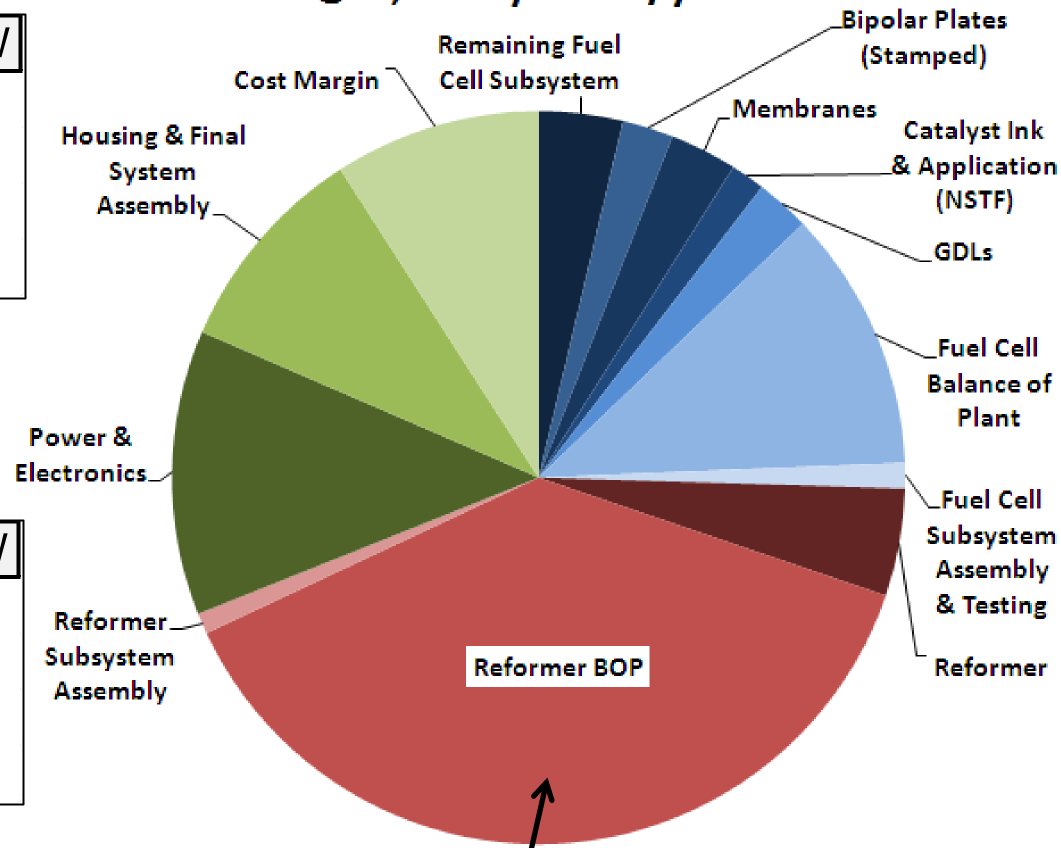
LT-PEM (~ 80 °C)

Sys/yr	1 kW	5 kW	25 kW	100 kW
100	$12K	$3.9K	$1.7K	$1.1K
1,000	$9.3K	$3.1K	$1.4K	$0.9K
10,000	$7.9K	$2.6K	$1.1K	$0.7K
50,000	$7.2K	$2.4K	$1K	$0.6K

HT-PEM (~ 160 °C)

Sys/yr	1 kW	5 kW	25 kW	100 kW
100	$11K	$4.2K	$1.7K	$1.3K
1,000	$8.8K	$3.3K	$1.5K	$1.1K
10,000	$7.5K	$2.8K	$1.2K	$0.8K
50,000	$6.9K	$2.5K	$1K	$0.7K

Cost Breakdown, 5 kW LT PEM @ 1,000 systems/year



Fuel processor is largest cost component for LT PEM and HT PEM

SOFC system analysis currently underway

**B. D. James et al., SA*

Fuel Cells Budget

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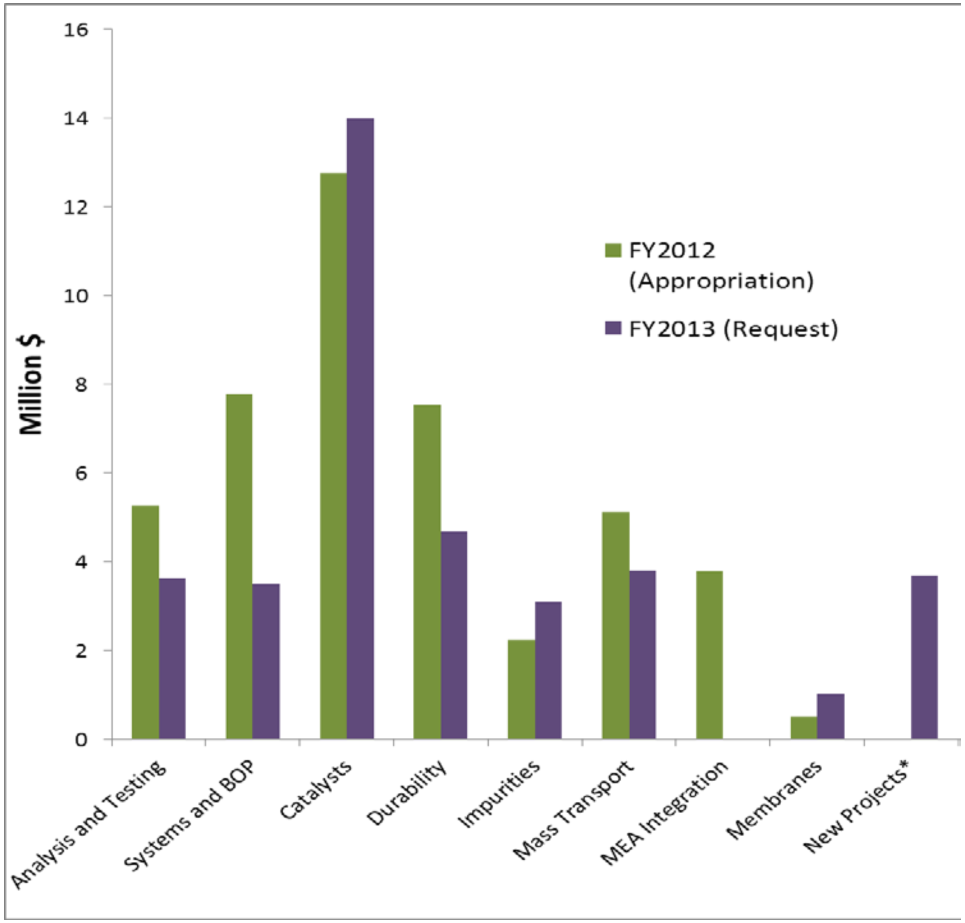
FY 2012 Appropriation = $45.0 M
FY 2013 Request = $38.0 M



Systems and BOP includes projects related to portable and stationary power

New projects in FY2012 for BOP and MEA Integration were fully funded up front

****Subject to appropriations***

EMPHASIS:

- Develop improved ultra-low PGM and non-PGM fuel cell catalysts and membrane electrolytes
- Improve PEM-MEAs through integration of state-of-the-art MEA components
- Identify degradation mechanisms and approaches for mitigating the effects
- Characterize and optimize transport phenomena improving MEA and stack performance
- Investigate and quantify effects of impurities on fuel cell performance
- Develop low-cost, durable, system balance-of-plant components
- Maintain core activities in components, subsystems and systems specifically tailored for stationary and portable power applications

Progress – Fuel Cells R&D

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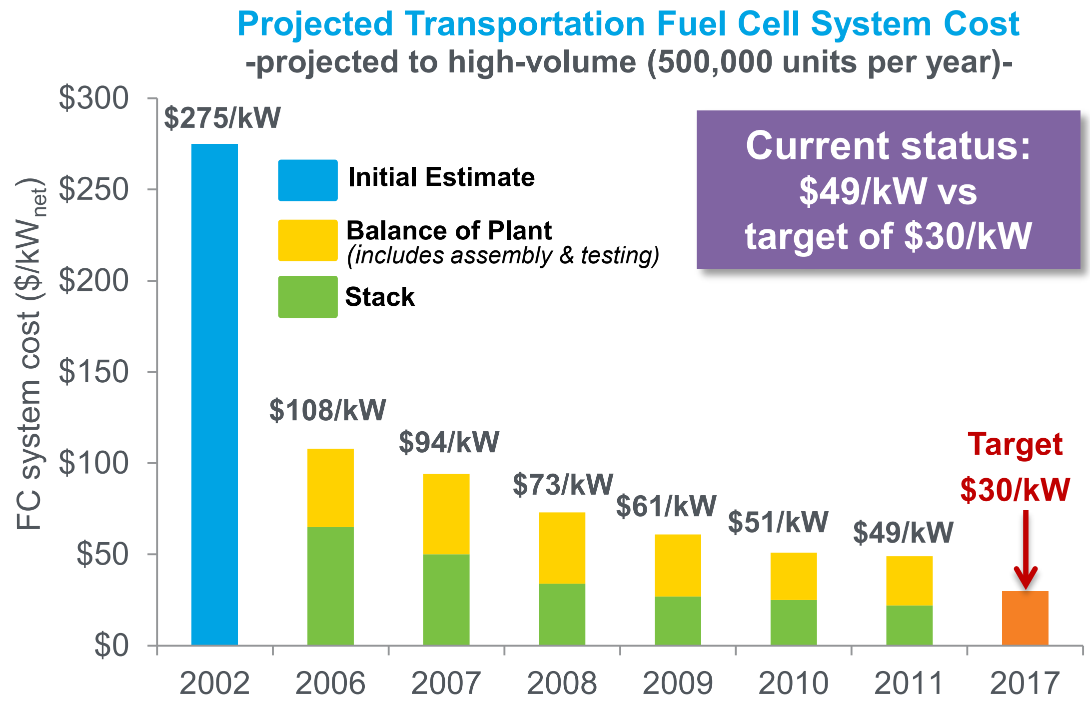
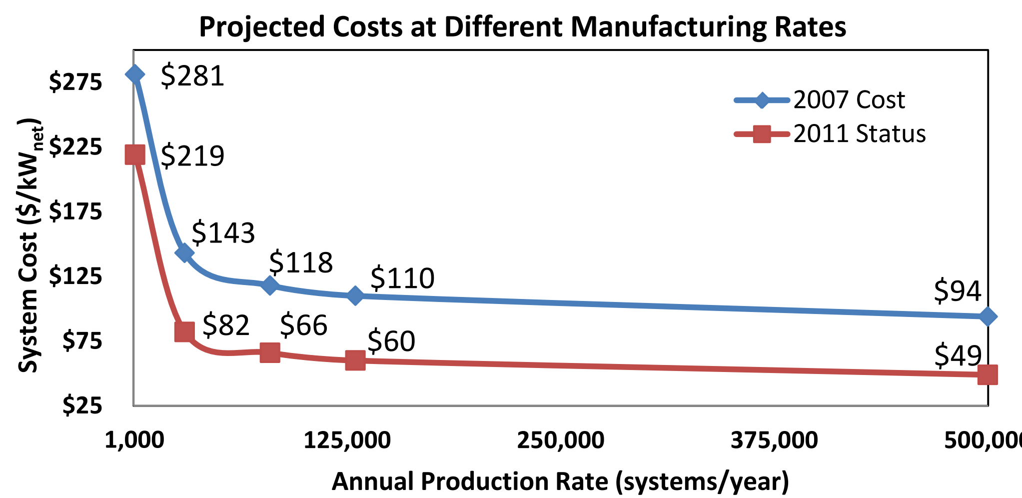
Projected high-volume cost of fuel cells has been reduced to $49/kW (2011)*

- ***More than 30% reduction since 2008***
- ***More than 80% reduction since 2002***





Based on projection to high-volume manufacturing (500,000 units/year). *The projected cost status is based on an analysis of state-of-the-art components that have been developed and demonstrated through the DOE Program at the laboratory scale. Additional efforts would be needed for integration of components into a complete automotive system that meets durability requirements in real-world conditions.*

Progress: De-alloyed Catalysts

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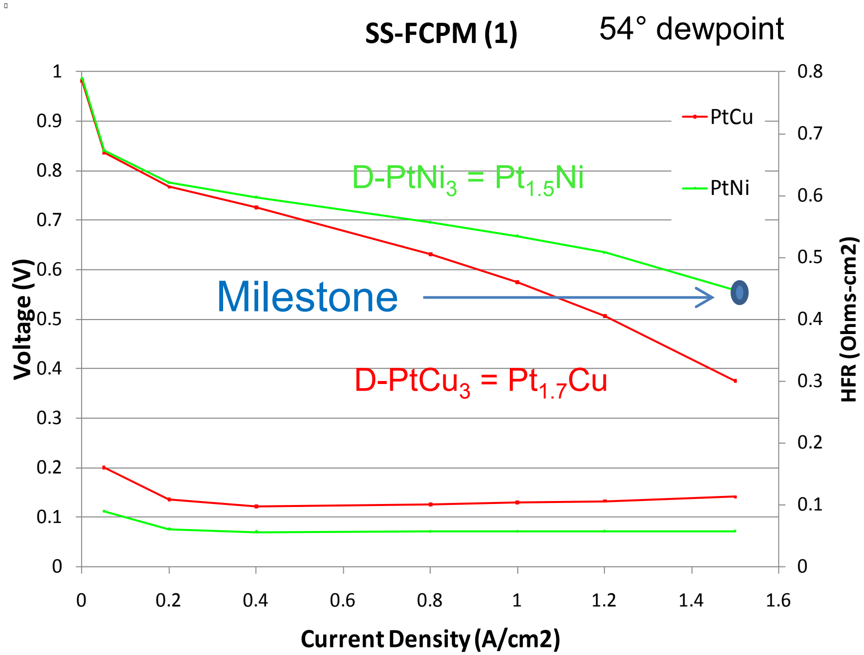
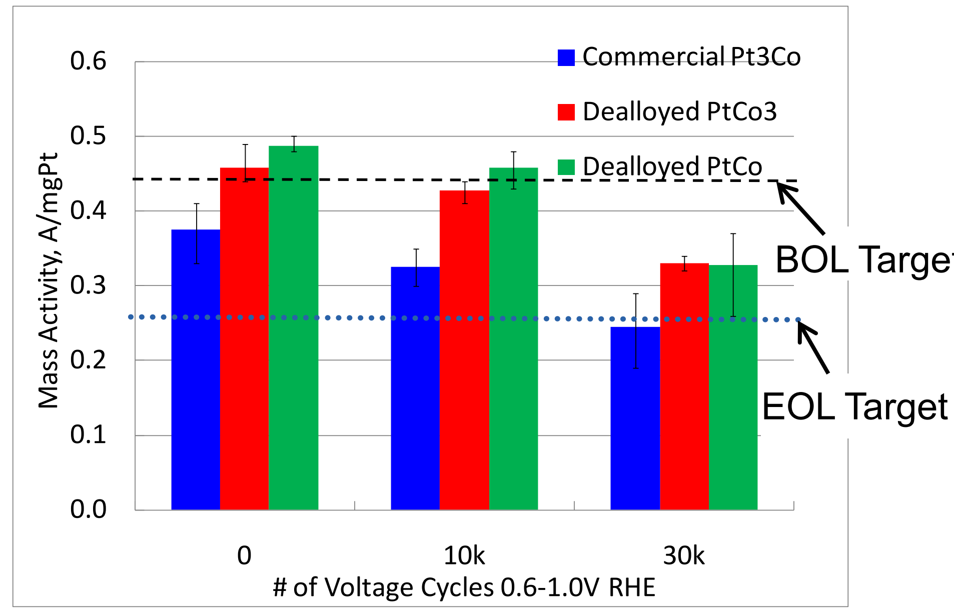
Low-PGM de-alloyed catalysts meet mass activity and durability targets.

GM 50 cm² MEAs, at 0.1 mg_{Pt}/cm^2
H_2/air, 80° C, 170 kPa_{abs}, stoichs 2/2



GM 50 cm² MEAs, 0.2 mg_{Pt}/cm^2



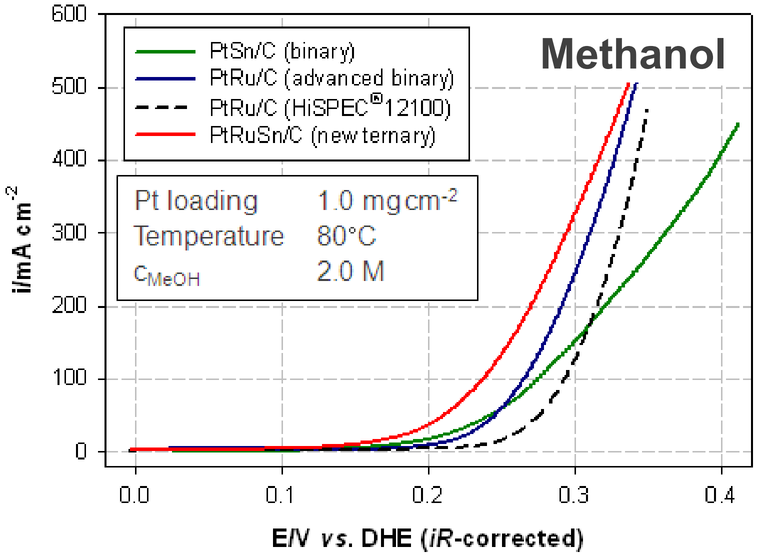
- $PtCo_3$ and $PtNi_3$ meet 0.44 A/mg_{PGM} mass activity target
- $PtCo_3$ meets 30,000 cycle durability target
- $PtNi_3$ meets 0.56 V @ 1.5 A/cm² milestone

0.46 A/mg_{PGM} for $PtCo_3$, 0.52 A/mg_{PGM} for $PtNi_3$ in 50 cm² MEA testing

F. Wagner et al., GM

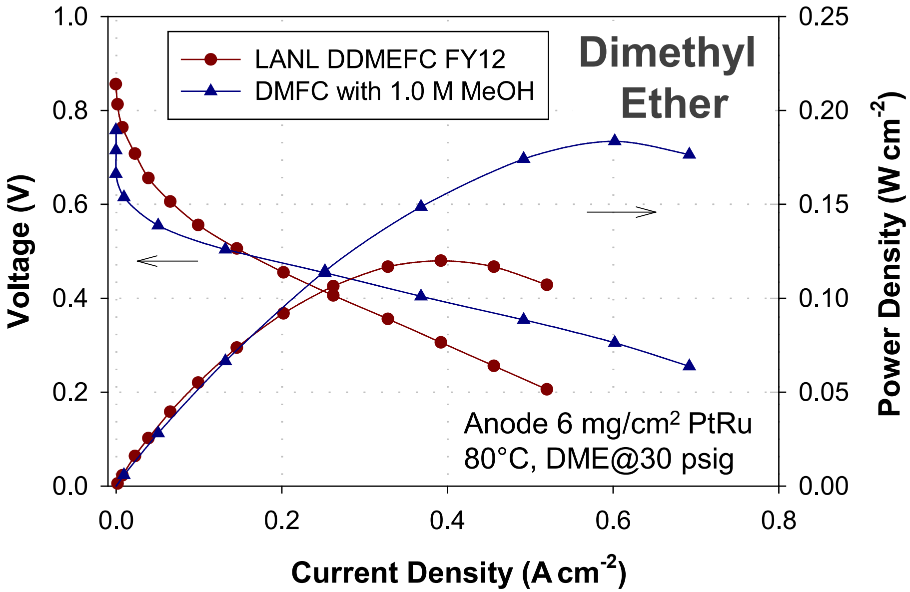
Progress: Portable Power

High-activity catalysts developed for liquid fuels



- JMFC's ternary PtRuSn/C DMFC catalyst combines advantages of PtSn at low overpotentials and PtRu at high overpotentials
- PtRuSn/C outperforms the best thrifted PtRu/C catalyst

PtRuSn/C methanol mass activity exceeds **500 mA/mg$_{Pt}$** at 0.35 V, **150% higher than FY12 milestone**



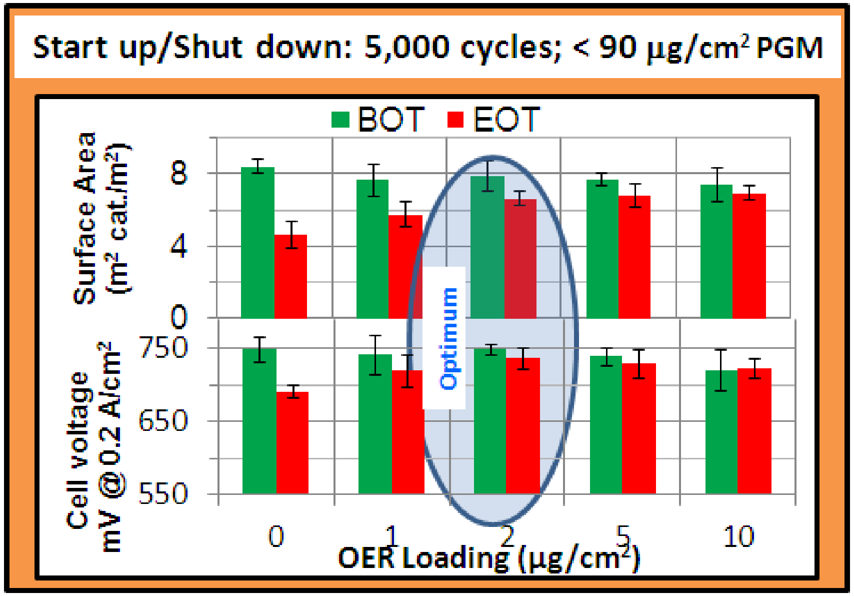
- DME fuel cell outperforms DMFC at low current due to **low DME crossover**

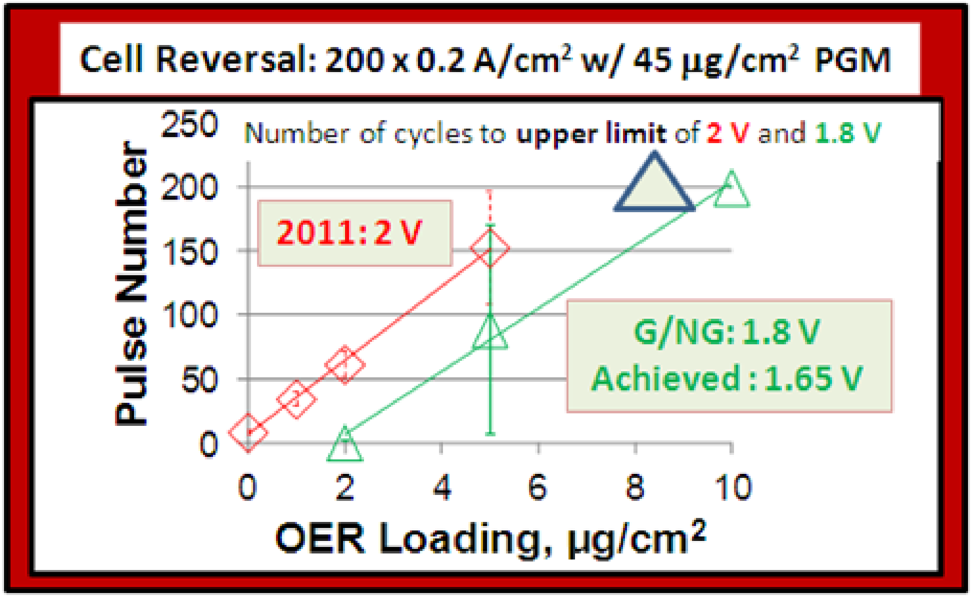
DME fuel cell achieves **150 mA/cm²** at 0.5 V – **60% higher than FY11**, **130% higher than best published data**

P. Zelenay et. al., LANL

Progress: Durable Catalysts

3M catalysts demonstrate durability under startup, shutdown, and cell reversal.





IrRu-modified cathodes have achieved the SU/SD Go/No Go requirement: 5,000 cycles with end voltage < 1.60 V, ECSA loss <10% with < 0.09 mg/cm² PGM

IrRu-modified anodes have achieved the cell reversal Go/No Go requirement: 200 cycles with end voltage < 1.80 V, with < 0.045 mg/cm² PGM

All Go/No-go milestones surpassed at:

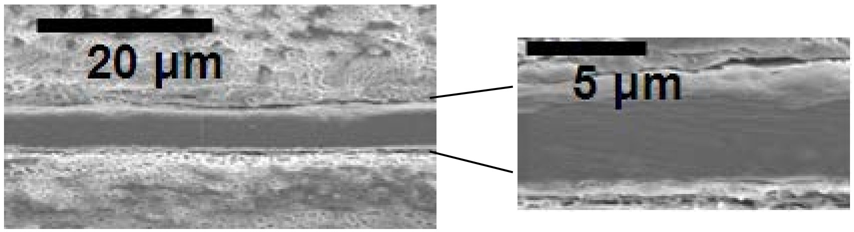
- **PGM loading < 0.135 mg/cm² total**
- **Voltages meet the set goals**

R. Atanasoski et al., 3M™

Progress: Balance of Plant

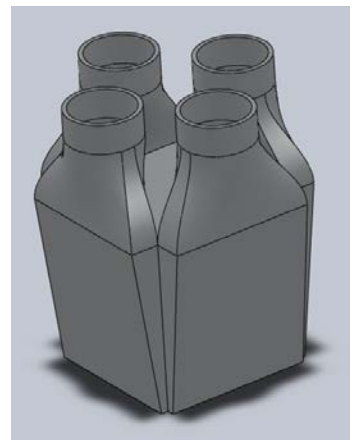
Compact, low-cost humidifier module projected to meet $100/unit 2017 cost target

High performance, cost-effective humidification membranes developed



Scale-up of these materials is underway

Flow field, pleat geometry and module design optimization to take advantage of very high transport rate materials, while maintaining low-cost assembly process.



Membrane pocket over plate assembly concept selected

- **Module performance consistent with single cell and *ex situ* testing shows loss of performance of 20-30% over 5500 hours**
- **Developed understanding of source of durability loss – chemical changes in PFSA**
- **Sub-scale module design complete, and sub-scale prototypes built and under test**
- **Final full scale module to be built**

Module cost estimated to be ~$100 at high volumes

W. B. Johnson et al., Gore®

Key Milestones and Future Plans

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FY 2012

- Updated Multi Year RD&D Plan & Targets Released
- Flow Cells Workshop
- Cost analysis projects initiated
- FOA Awards Announced
- RFI for MHE released

FY 2013

- New FOA* Awards
- Develop an experimentally validated model describing mass transport in PEMFCs.
- Cost analyses updates
- Develop truck APU with projected durability of 10,000 hours, at a cost of $1400/kW, operating on standard ultra-low sulfur diesel.

FY 2014

- Develop a 10-fold accelerated test for high-temperature fuel cell durability testing
- Develop PEM bipolar plates with a cost less than or equal to $5/kW

** Subject to Appropriations*

New Fuel Cell Projects

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5 new projects announced in FY 2011 (cost analysis) and FY 2012 (R&D) — total award of ~$10M

Cost Analysis

Transportation (Strategic Analysis)

- **Analyze and estimate the cost of transportation fuel cell systems for use in vehicles including light-duty vehicles and buses**

Stationary and Emerging Markets (Battelle, LBNL)

- **Develop total cost models and provide cost assessments for stationary and emerging market fuel cell system technologies**

Research & Development

MEA Integration (3M)

- **Approach is based upon integration of 3M's state-of-the-art nanostructured thin film catalyst technology platform with other components of the MEA**

System BOP (Eaton)

- **Develop and demonstrate an efficient and low-cost fuel cell air management system**

STRATEGIC ANALYSIS
Battelle The Business of Innovation
BERKELEY LAB
3M
EATON Powering Business Worldwide

Session Instructions

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- This is a review, not a conference.
- Presentations will begin precisely at scheduled times.
- Talks will be 20 minutes and Q&A 10 minutes.
- Reviewers have priority for questions over the general audience.
- Reviewers should be seated in front of the room for convenient access by the microphone attendants during the Q&A.
- Please mute all cell phones and other portable devices.
- Photography and audio and video recording are not permitted.

Reviewer Reminders

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- Deadline to submit your reviews is **May 25th at 5:00 pm EDT.**

- ORISE personnel are available on-site for assistance.
  - **Reviewer Lab Hours:** Tuesday – Thursday, 7:30 am – 8:30 pm; Friday 7:30 am – 1:00 pm.
  - **Reviewer Lab Locations:**
    - Crystal Gateway Hotel—Rosslyn Room (downstairs, on Lobby level)
    - Crystal City Hotel—the Roosevelt Boardroom (next to Salon A)

- Reviewers are invited to a brief feedback session – at 5:45 pm Thursday, in this room.

For More Information

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Principal Participating Organizations

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- **Testing and Technical Assessments**
  - Battelle
  - LBNL
  - LANL
  - Strategic Analysis
  - NREL
  - ANL
  - ORNL
  - NIST
- **Balance of Plant**
  - W. L. Gore & Associates
  - Eaton
- **Catalysts & Supports**
  - BNL
  - PNNL
  - 3M
  - LBNL
  - ANL
  - LANL
  - General Motors
  - Northeastern University
  - University of South Carolina
  - Illinois Institute of Technology
  - NREL
- **Durability**
  - Ballard
  - LANL
  - ANL
  - Nuvera Fuel Cells
  - Dupont
- **Impurities and Fuel Processors**
  - NREL
  - University of Hawaii
- **Membranes**
  - Giner Inc.
  - University of Central Florida
  - Ion Power
- **MEA Integration**
  - 3M
- **Portable Power**
  - Arkema Inc.
  - LANL
  - University of North Florida
- **Stationary Power**
  - Acumentrics
  - UTC
  - Innovatek
- **Mass Transport**
  - SNL
  - LBNL
  - Nuvera Fuel Cells
  - Giner Inc.
  - General Motors